Antecedents of Future 6G Mobile Ecosystems

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***Abstract*—This paper applies an integrative, futures-oriented action research methodology to explore the antecedents of future 6G mobile communications ecosystems. Based on extant ecosystem research, the paper develops a conceptual framework to depict and analyze mobile communications ecosystems. The developed framework is used for analyzing future 6G mobile communications ecosystems by looking at ecosystem contingencies, structures, process, goals, and outcomes, and it briefly discusses the key transformations anticipated for 6G mobile ecosystems. The results indicate that 6G will bring about fundamental structural changes to the mobile ecosystem, calls for novel models of ecosystem governance and regulation that highlight privacy, security, environmental sustainability and societal resilience.**

Keywords—6G, business, ecosystem, antecedents.

I. Introduction

Ecosystem thinking has evolved from being only a contemporary metaphor to becoming *the tool* for making sense of newly emerging and transforming business contexts. Ecosystems are currently widely used in business research to reconcile, complement, and improve earlier discussions on industrial architectures, clusters, platforms, networks, supply chains, value chains, and markets [1] - [5]. In generic terms, the Encyclopedia Britannica [6] defines an ecosystem as the "*complex of living organisms, their physical environment, and all their interrelationships in a particular unit of space*." Beyond ecological definitions, different but parallel and partially overlapping ecosystem conceptions can be found in the extant literature for business-related research: industry ecosystems, regional ecosystems, innovation ecosystems, entrepreneurship or entrepreneurial ecosystems, business ecosystems, and digital business ecosystems [7]. Recently, studies have also begun to focus on platform ecosystems [8]. As a result of the integrative nature of the ecosystem concept, it is becoming one of the richest and deepest tools for analyzing, depicting, and understanding various contexts, also industrial [9], for doing business in the future.

The mobile communications industry has for a long time been referred to as an ecosystem [10] [11]. Unfortunately, quite a few actual mobile communications ecosystem descriptions exist in the literature. As an overview, the authors in [10] present the 3G ecosystem. The authors in [11] discuss the mobile telecommunications ecosystem evolution and present the current 4G-dominated ecosystem, starting from hardware providers, software providers, facility and equipment managers, network operators, content providers, OTT (over-the-top) internet players, service providers, such as MNOs (mobile network operators) and MVNOs (mobile virtual network operators), and concluding with end users. The authors in [11], present a value chain and network view on the topic rather than an ecosystem viewpoint. Although the deployment of 5G networks has already started, little research has been done on the 5G ecosystem [12] [13] as such.

The transition from 5G to 6G towards 2030 will be a sequential process for various verticals. The emerging 6G ecosystems [14] should thus be seen from the viewpoints of various ecosystem conceptions, warranting an integrative approach. The authors in [15] note that software-based components, services, and applications could be regarded as "digital species" in the global selection process. Indeed, any digital species, including those embedded in the future 6G ecosystem, could be seen as evolving in an ecosystemic context through the evolutionary process of variation, retention, and selection [16].

Currently, the forces influencing the change from 5G to 6G ecosystems, as well as how it will occur and the possible outcomes of this change, remain an open question. Already 5G has been referred to as a disruptive change for the whole mobile communications industry [12]. Future 6G ecosystems, the focus of this paper, do not exist yet. In order to explore these ecosystems, this paper seeks to address the question, *what are the antecedents of the future 6G ecosystems?* To answer the question and to achieve a true ecosystem analysis, the paper proceeds as follows. Section II starts by defining what is meant by and how to approach ecosystems and ecosystemic change, and it outlines a framework for depicting and analyzing change in future ecosystems. In addition, the section includes the first attempt to describe the 6G ecosystem. Section III presents the integrative anticipatory action research methodology used in the paper. Section IV discusses the analysis and future 6G ecosystems based on the developed framework. Section V draws conclusions and highlights selected perspectives for future study.

II. Theoretical Approach To Ecosystems

This section reviews the theoretical foundations of the paper and presents the current understanding of the mobile communication ecosystem.

A. Defining Ecosystem Concept

A variety of ecosystem conceptions exist in various fields of research. Such integrative or systemic ecosystem research papers as [3] [9] [1] [17] attempt to define the ecosystem concept. The authors in [3] find four approaches to ecosystems in the extant literature: the industrial ecosystem perspective, the business ecosystem perspective, the platform management perspective, and the multi-actor network perspective. They also claim that a coherent conception of an ecosystem rests on the boundary-setting criteria, a definition, the actors and their attributes within the ecosystem, the dynamics of the ecosystem interaction in terms of behavior, decision-making, and interaction (visible and invisible resource flows, contracts, trust, and vision sharing). The authors in [3] do provide a definition for the ecosystem for managing technology and innovation: its aim is "*to provide a product/service system, an historically self-organized or managerially designed multilayer social network consists of actors that have different attributes, decision-principles, and beliefs*." In turn, the authors in [1] define an ecosystem as "*a set of actors with varying degrees of multilateral, non-generic complementarities that are not fully hierarchically controlled*." They point out the importance of coordination, collaboration, value creation and capture, governance, and regulation for understanding ecosystemic dynamism.

Beyond pure definitions, and as an attempt to depict ecosystems, the authors in [18] present an ecosystem pie model that depicts the resources, activities, and value addition and captures elements for ecosystem players that strive for a common value proposition. The authors in [19] present the ecosystem on a canvas using the metaphor of a rainforest. They note that in an ecosystem, attention needs to be paid to resources, stakeholders, the leaders of the ecosystem, activities, engagement, role models, frameworks (i.e., regulation), infrastructures, capabilities, community, and culture. The authors in [4] present a coherent logic for depicting ecosystems that includes four types of elements: *ecosystem contingencies*, which include policies and regulations, cultures and institutions, and the economic industrial base, *ecosystem structures*, which include stakeholders, roles, and relationships, *ecosystem processes*, which include knowledge sharing and spillover, business and experimentation, the emergence of new stakeholders, and scale-up, and finally, *ecosystem goals and outcomes*. Fundamentally, ecosystems are opportunity-driven and based on the digital and spatial affordances (i.e., resources/assets) that the environment offers. Figure 1 summarizes the ecosystem conception presented in [4].

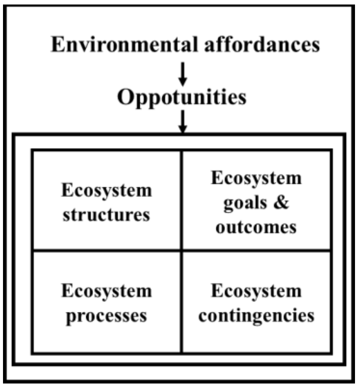

Fig. 1. The four elements for depicting ecosystems [4].

Thus, ecosystem contingencies may consist of transitional regulative, business, and technological elements [20], which cover regulations regarding spectrum usage and licensing, data transmission and rights, as well as consumer protection and competition. Technical standardization represents another key facet in the development of the wireless communications ecosystem. On the business side, attention needs to be paid to the scale and scope effects prevalent in the industry [21]. Ecosystem structures consist of the various actors as well as resources and assets. Regarding assets, complementarity is a key feature.

The extant literature recognizes three types of complementarity: generic, specialized (to a purpose), and co-specialized (in collaboration) complementarity [22]. An ecosystem's key processes consist of innovation, coopetition (i.e., parallel competition and collaboration), governance, and value-related activities [4] [23]. The ecosystem's goals and outcomes may comprise scalability and the replicability of resources, assets and services, and sustainability and the resilience of practices [4] [24] [21]. Density, fluidity, connectivity, and diversity are the key measures for successful ecosystems [25]. Thus, achieving systemic understanding [26] calls for drawing attention to the connections between the components of a system, thus highlighting a system's elements or structure and the process through which the system emerges and becomes—also over time [9].

B. The Mobile Communications Ecosystem

In the extant literature, the 5G ecosystem consists of mobile operators, mobile equipment and infrastructure vendors, regulative bodies, content and application providers, network infrastructure constructors, facility owners, and the end users [13]. Adopting a value perspective, [12] presents three types of ecosystem structures for 5G: vertically, horizontally, and obliquely organized. With 5G [11], changes in the ecosystem are expected to take place in the market positions of various existing access providers, RAN (radio access network) outsourcing players, IoT (internet-of-things) players, content owners, and OTTs, and new players are expected to emerge among connectivity, asset, cloud (also edge cloud), and partner service providers.

The authors in [14] suggest as many as 29 stakeholders in the future 6G ecosystem, categorizing them into human, machine, enterprise, and public-sector type users, each with different *demands and needs*. *Matching and bridging* stakeholders consist of the mobile virtual network operator, mobile network operator, fixed operator, satellite operator, vertical-specific service provider, roaming service provider, application provider, digital twin provider, management service provider, data broker, network resource broker, broking/bridging provider, trust provider, and providers of security as a service. *Resource and asset* stakeholders consist of the device supplier, network/cloud infra vendor, complementary technology provider, national regulator, public sector, government, data owner, context provider, content provider, context owner, edge cloud, data center, facility owner, site supplier, and building constructors.

III. Research Methodology

Next we present the research methodology applied and the data analysis. This study applies an exploratory and futures-oriented *integrative anticipatory action research method.* Integrative approaches to the future highlight the importance of integration and a of multiplicity of worldviews and data that is well suited to ecosystemic contexts [27]. Action research approaches highlight the importance of representative participation. The author of [28] advocate paying attention to constructs (i.e., ecosystem framework), contents (i.e., data used), capacities (i.e., representative stakeholders), and conditions (i.e., contextual focus) when applying the integrative approach. The integrative research process in this study followed a cycle of four steps; first (inputs), appropriate inclusive methodologies were used to gather information from, and about, the contextual environments relevant to the focus; second (unfoldment), the data used to determine driving forces, their casual chains, and critical uncertainties in the focus were analyzed; third (enactment), different interpretations and relationships between the key variables in focus were investigated, while still maintaining consistency; and fourth (un-comfort), outcomes, including theoretical outcomes, and their implications were communicated to relevant parties for application [29] [30].

This research partially used findings from workshops held at the 6G Wireless Summit in Levi, Finland, in 2019. The constructs, contents, and conditions required by the author in paper [28] are presented in the form of a theoretical framework and data presented, and appropriate capacities have been ensured via the inclusive and representative action research workshop held at the 6GSummit. The first-round outcomes and findings have been presented in the form of a report [14], and the continued second-round outcomes are presented in this paper.

IV. Future 6G Ecosystems

For conducting futures-oriented research, authors in [31] advise conjoining the weight of the past, the push of the present, and the pull of the future in the analysis. The following exploratory analysis will start with 6G ecosystem contingencies, continue with structures and processes, and conclude with goals and outcomes.

A. *6G Ecosystem Contingencies*

The formation and emergence of future 6G ecosystems are based on the flexibility of its key structures. Two key elements influencing flexibility may be recognized: regulation and standardization. The traditional view on regulation has been to tightly regulate the telecommunication service provider market. In particular, spectrum regulation has been a major tool in governing the mobile communication market by defining the rules and conditions for operating cellular mobile communication networks. Spectrum regulation is concerned with the availability, access to, and fairness of *spectrum* assets and competition between operators to ensure public benefits. With 6G, new demands may be placed on regulations that concern access to and ownership of *data* and the use of algorithms, such as artificial intelligence, in processing data, especially for *privacy* and *security* purposes. These demands are also reflected in concerns over 6G systems' *resilience* for society. There is also controversy regarding the new concepts of virtualized network-based services, the *Net Neutrality* regulation, and further anticipated changes in industry structures with respect to 6G. Current regulations do not consider SOA-based (service-oriented architecture) tailoring regarding, for example, traffic management, resource allocations, redundancies, and novel edge security. Furthermore, network virtualization that utilizes cloud technology is not included; for instance, OTT (over-the-top) cloud services are unregulated, while mobile network operators in Europe are subject to Net Neutrality regulations.

Already 5G has shown the increasing importance of *local space* as future mobile networks utilize higher frequencies and are deployed indoors enabled by local spectrum licenses. It may be anticipated that with the even higher frequencies of 6G, the role of local space or context will become more pronounced as a contingency since the needs and demands of 6G users may vary considerably over time. A restructuring of the industrial base via 6G is expected. Related to the role of local spaces, the conflicts of different standardization cultures must be resolved. It is no longer sufficient to standardize mobile technologies only; it is imperative to collaborate across different industrial standards, many of which remain today of a de facto nature. At the same time, increasing environmental, climate, and health concerns (e.g., the impact of electromagnetic fields) highlight the importance of *sustainability* in 6G solutions.

B. *6G Ecosystem Structures*

The actors and their resources in the 6G ecosystem are expected to change and new actors will emerge. Already with 5G, *local operators* that combine connectivity and local content/context services will continue to develop. The increasing need for trust is expected to trigger new types of *trust providers* and trust services, such as blockchain-based or Mydata-based transaction services or platforms. Traditionally, vertically structured industries may converge or diverge to facilitate innovation, and beyond that, telco institutions may emerge to provide horizontal services. The increased *platformization* of businesses may lead to transformations in the traditional vertically, horizontally, or regionally structured business models to increasingly oblique models, that is, models that enable contextualized and/or personalized services anywhere through novel collaborative and disruptive combinations. These developments will create a need for more transparent and dynamic data management structures, especially with respect to customers' personal data (incl. Mydata).

Changing customer behavior, as well as service needs and experiences, might break the dominance of the traditional telco *customer relationship*. As users perceive connectivity more and more as a basic utility, the role of OTT and other content players may become further strengthened in customer relations. Moreover, for highly specialized private enterprise networks, the role of technology vendors as customer interface providers could become dominant. Various connectivity operators of different scale and scope are expected to coexist, highlighting the role of *asset complementarity*, which in turn may mean the increased importance of co-specialized assets, especially in the case of cloud and edge cloud platforms, while spectrum resources might increasingly become more generic. On top of human and machine users, the emergence of independent, AI-based (artificial intelligence) algorithms and machines as users may require different types of specialized network assets.

C. *6G Ecosystem Processes*

The change drivers of the 6G ecosystem include technical and business model *innovation* and various spill-over effects. In the technical innovation stream, the integration of communication and sensing capabilities in 6G among other things will enable the creation of new solutions and open up new business opportunities, further enabling new ways of value creation and capture. The same holds true for the extensive use of artificial intelligence algorithms. New forms of *value flows* (value creation-capture-sharing) may be expected to emerge as data with algorithms comes to be seen more as "reusable" or as "currency" for better services and customer experience than as "oil."

Coopetition, the parallel competition and collaboration between different stakeholders within the ecosystem, is expected to increase as competition for and within local contexts (e.g., edge clouds) will increase between traditional and new ecosystem members. Matching and bridging different resource (i.e., spectrum, computing, storage, data) needs and services between various users and uses may also trigger novel modes of *governance* between ecosystem stakeholders. More contextual, open, and fair governance approaches are to be expected. In addition, the governance of artificial intelligence algorithms may also pose entirely new issues for 6G.

D. 6G Ecosystem Goals and Outcomes

The novel goals and outcomes for future 6G ecosystems may be expected to technically stem from *cloudification*, especially edge clouds, and the *near real-time* communications of 6G. The ubiquitous wireless intelligence enabled by artificial intelligence and reusable data influence the ways in which new *economies* of scale and scope may be reached. Data economies of scale utilized by artificial intelligence and context/location economies of scope and competences may increasingly emerge built on modular service structures, but also based on synergies and complementarities, that is to say, ecosystemic connectivity between the different interacting, also novel, stakeholders.

6G is expected to become more *inclusive* and driven by social fairness, thus enabling smaller firms and new entrants to bring more diversity and fluidity to 6G-based services. Also, new application areas are expected to emerge within industries and agriculture. Ensuring *resilience* and security are expected to become key challenges for 6G-based critical infrastructures, warranting the use of artificial intelligence and trust services. Finally, the *sustainability* of 6G solutions in terms of recycled materials and energy efficient operations is expected to gain in importance, as are concerns over electromagnetic fields.

V. Revolution or Evolution of 6G Ecosystem?

The analysis of the available data is indicative of both evolutionary and revolutionary antecedents of future 6G ecosystems. Table 1 highlights these changes. Regarding ecosystem contingencies, with 6G it is anticipated that the emphasis on regulation will change from spectrum and competition to data security/privacy, environmental sustainability, and societal resilience. A new cross-domain standardization culture is expected to emerge. In addition, a controversy has arisen from within the new concepts of virtualized network-based services and OTT services regarding Net Neutrality regulation, which in turn may lead to changes in the structure of the mobile communications industry.

Regarding ecosystem structures, with 6G it is anticipated that the importance of local context and novel trust providers will increase. Platformization and the related convergence and divergence of value structures may enable contextualized and personalized services anywhere and make earlier vertical and horizontal industry structures oblique. In addition, more transparent and dynamic data management is called for. Virtualization may change technology innovation ownership, while changing customer behavior may result in changes to customer ownership in the value chain from connectivity providers towards OTT services and experiences. It may be expected that spectrum becomes a generic asset, whereas artificial intelligent will require specialized assets and edge clouds co-specialized assets.

Regarding ecosystem processes, innovation in the areas of combined communications and sensing as well as data and intelligent algorithms will enable novel value flows via novel and revolutionary solutions, influence asset complementarity between stakeholders, and increase coopetition instead of traditional competition. New forms of governance as well as trust providers are expected to complement missing regulations in areas where new forms or partnerships of collaboration emerge.

Regarding ecosystem goals and outcomes, inclusivity and fairness of mobile services are expected to gain in importance in future 6G ecosystems. New areas of application within industries and agriculture are expected to emerge. It is also expected that new economies of scale and scope will emerge from data/algorithms and local contexts, respectively. Demands for environmental sustainability and societal resilience, but also for individual privacy and security, will bring about novel requirements for the developed 6G solutions.

TABLE I. Antecedents of future 6G Ecosystems

Ecosystem element	**Description**
Contin-gencies	Emphasis on regulation changes from spectrum and competition regulations to highlighting users' privacy and security, net neutrality, environmental sustainability, and societal resilience. Novel cross-domain technical standardization culture will emerge.
Structures	Importance of local context and need for trust will increase; novel stakeholders will emerge. Platform-based collaboration will transform vertical and horizontal value structures into oblique ones. Novel, virtualized, service-oriented network architecture may change technology innovation ownership, while customer ownership may change from connectivity providers towards OTT services and experiences. There is increased need for more transparent and dynamic data management structures. Spectrum will increasingly become a generic shared asset, while the importance of specialized assets will increase due to artificial intelligence. Edge clouds will be important as a co-specialized asset.
Processes	Innovations with combined communications and sensing capabilities, as well as data and algorithms, will enable novel value flows, influence complementarity between stakeholders, and increase coopetition instead of traditional competition. Novel forms of governance as well as trust providers will come to complement regulation.
Goals & Outcomes	Fairness and inclusivity and new application areas within industry and agriculture will be key drivers in the early development of 6G. Artificial intelligence algorithms, reusable data, and near real-time communications-related innovations will be used as a basis for scaling and replicating solutions. Sustainability and resilience will be targets for 6G solutions.

VI. Conclusions

This paper has aimed at identifying and exploring the antecedents of future 6G ecosystems. The paper adopted a conceptual framework to depict ecosystems and ecosystemic changes, with a specific focus on the changes anticipated to take place when transitioning to 6G ecosystems. The research method used was integrative anticipatory action research. The analysis covered ecosystem contingencies, structures, and processes as well as goals and outcomes. Extant research on 6G is still scarce, and this paper represents the first attempt to depict the ecosystemic changes towards future 6G.

Our findings are indicative of a creative destruction and restructuring of existing mobile communications ecosystems via both gradual evolutionary and disruptive revolutionary technological changes and the emergence of new roles and stakeholders within the ecosystem. While 6G may help the mobile industry to converge with many traditional industries, this convergence may also lead to the divergence of traditional vertical and horizontal value flows and value structures. More dynamic and forward-looking strategies might be required in the future from existing stakeholders in the mobile ecosystem. The first key research challenge identified by this paper is as follows: *What kind of novel ecosystem-oriented strategies might emerge and be competitive in future 6G environments?* In addition, concerns over privacy, security, transparency, and fairness—as well as health, environmental sustainability, and societal resilience—are expected to bring about new demands for the regulation, standardization and governance of economic activity and solutions within 6G. Since 6G may be expected to be decisive for the competitiveness and sustainability of our economies, this paper sees the second key future research challenge to be as follows: *What kind of novel regulation, standardization, and governance models might emerge and be competitive in future 6G environments?*

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